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Long-term monitoring of thermo-technical properties of lightweight constructions of external walls being exposed to the real conditions

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Abstract

The article describes the results of long-term measurements of thermo-technical characteristics of lightweight sandwich external walls suitable for using in passive wood-based buildings. Monitored were the samples of walls, which were built into the external wall of the climatic chamber of pavilion type during four years of their exploitation. Inside the chamber, the stationary climatic conditions were maintained throughout the whole year and from the exterior side, the samples were exposed to the real weather conditions. The results of selected monitored thermo-technical parameters are presented, such as: temperature, water content in insulation materials and coefficients of thermal conductivity of materials incorporated in the compositions of the walls.

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Keywords: Wooden houses; Light-weight external walls; Energy performance of buildings; Real external conditions; Thermo-technical properties

1. Introduction

The sandwich outer wall was designed and realized in all alternatives in thermal-technical standard for passive buildings. Comparing to standard constructions it differentiates from them with the inverse range of layers, i.e. thermal-accumulating layer is situated from the exterior and the thermal-insulating layer is situated from the interior side of the wall construction, so as we know it from some layer compositions used in Nordic countries.

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Nomenclature

θ_{ae} – exterior air temperature
w – water content in material
m_w – weight of wet specimen
m_d – weight of dry specimen
λ – thermal conductivity coefficient

2. Description of the experiment

Dimensions of monitored experimental wall are 3670 x 2670 mm and it consists of 5 fields (Fig. 1). They differ from each other with material composition and surface coloring. Fields 1, 2, 4 and 5 are diffusional closed constructions and the third field is a diffusional open construction (Fig. 2). Temperature measurements were carried out on a sample of light-weight sandwich outer wall, built in a climatic chamber of pavilion type in the Laboratory centre of the Department of civil engineering and urban planning, Faculty of Civil engineering, University of Zilina. The temperatures were recorded in the 30 minutes time period in the fragment: exterior surface, under the coating, inside surface of the MDF board and inside surface of the infill thermal insulation. Several sensors are located also on the wood columns. More detailed description is in [1]. Parameters of the indoor climate, relative humidity and indoor air temperature were maintained by the air condition unit and set to temperature of 20 °C and a relative humidity of 50%, from the exterior were fields of test walls exposed to the actual conditions of the external climate. The parameters of the external environment were recorded by the experimental detached weather station at the same time step and captured were the following ones: temperature and relative humidity of external air, wind speed and direction, intensity of the global solar radiation on the horizontal plane and the vertical plane identical to the orientation of the test wall. After four years of exploitation, in autumn 2014 (before the cold period of the year) and in spring 2015 (after the cold season of the year), there were measured mass moisture in thermal insulation as well as the thermal conductivity coefficient of incorporated materials. Mass moisture of fibrous thermal insulation and fibreboard (MDF) was determined by the gravimetric method [2]; mass moisture of wooden support posts by the capacitive moisture measurement device Greisinger GMH 3850 (accuracy 0.01%). Thermal conductivity of the fibrous thermal insulation was measured with the Isomet 2104.

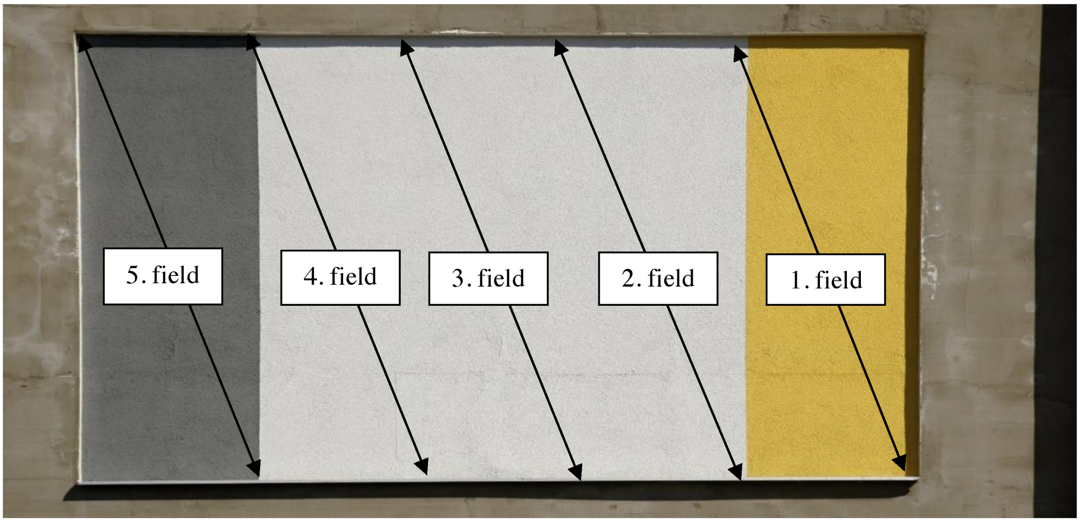

Fig. 1 Exterior view at the experimental wall (3670 x 2760 mm) with marked five different fields.

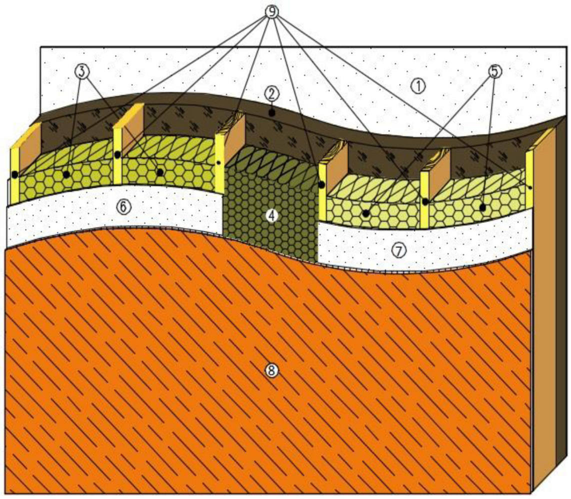

Fig. 2: Tested wall - left view from the exterior; right composition of layers: 1 - external plaster 4 mm; 2 - MDF fibreboard Hofatex 100 mm; 3 - stone wool 220 mm; 4 - hemp mat 220 mm; 5 - mineral wool 220 mm; 6 - PE vapor membrane; 7 – vapor barrier with changeable diffusional resistance 8 - OSB board 12 mm; 9 - wooden columns 60 x 220 mm.

3. Results of the experiment

To show long-term temperature measurement results in different layers of the wall, there was chosen 1-week measurement in the cold year season [1] from 27.1 - 2.2.2012 ($\theta_{ae, min}$ = -18.9 °C, $\theta_{ae, max}$ = 4.6 °C). Outer surface temperatures of each field are shown in Fig. 3.

Different temperatures in the structure were affected not only by its material composition, but also by natural influences of the environment as well as the different light absorption and reflectance caused by coatings. Highest surface temperatures were measured on the grey coating. Such a coating has the lowest reflectivity of solar radiation and absorbs most short wave solar radiation. Maximums during clear days were above 48 °C, and higher by about 30 °C when compared with other surfaces. Of the fields with white coating, field No. 3 had the lowest surface temperature which is caused by the higher heat flow. During nights of the whole reference week the surface temperature in all fields was lower than the ambient air temperature due to the cold sky radiation. At this time, the minimum temperatures were recorded mainly in the fourth field with white finish, and the first field with yellow finish [3]. Significant influence of deviation of external conditions at the temperature course in the construction was noticed in monitored positions closest to the interior under the additional thermal insulation MDF board Hofatex. On the border between the infill insulation and OSB plate it was observed more significant impact of the technology of internal environment (AC unit used to maintain the indoor climate). During winter the warm-up mechanism had a positive effect on cooling structures leading to the heat loss of the building, since the minimum temperature of the additional heat insulation layer, and hence the greatest cooling storing layer was due to the thermal inertia and its associated phase-shifting temperature oscillation recorded at the time when the test wall from the outside, once again exposed to sunlight and is therefore once again the accumulated energy (those relied on Anderson [4]). In winter, thus mitigating action was cold outside environment by changing boundary conditions and thus reduce heat loss through the test wall.

During the winter period the mechanism of heating and cooling process had positive effect on heat loss of the building, because minimum temperatures under the additional insulating layer and therefore the largest cooling of storage layer was thank to the thermal inertia and with it connected phase shift of the temperature oscillation recorded in time, when the tested wall was from the exterior side exposed to the solar radiation and therefore its energy was accumulated [4, 5]. By finding out properties of individual thermal insulations after 4 years from assembling it was observed, that by 24-hour testing of thermal conductivity coefficient of fibrous insulations this changed during the day only minimal or insignificantly (Tab. 1). By 24-hour testing in the additional insulation MDF board Hofatex, there were monitored significant changes in all of the fields, mostly in the 5th field with grey finish.

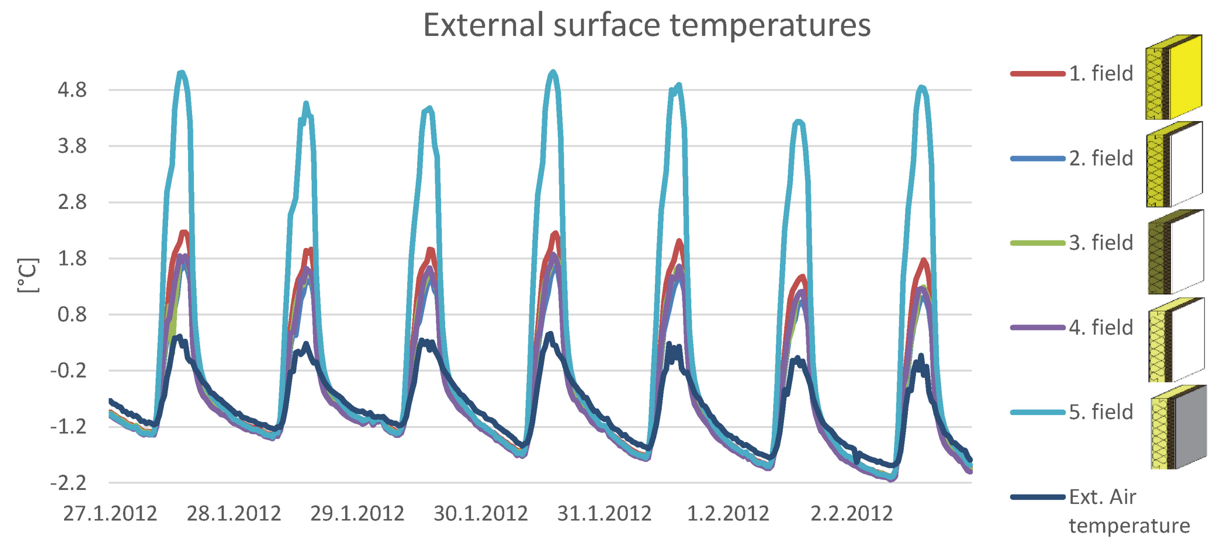

Fig. 3: Temperature courses at the exterior surface of the construction for dates 27.1. - 2.2.2012. Colored surface finish yellow (first field), white (second, third and fourth field) and grey (fifth field).

As next it was observed, that while in fields with the diffusional closed compositions the thermal conductivity coefficient stayed nearly the same according to declared values, the thermal conductivity coefficient of the hemp thermal insulation increased by moisture transport up to 30 %.

Measured values of the coefficient of thermal conductivity λ were ranged from <0.0621; 0.0637> W/(m.K). For this reason, it_seems more appropriate to use structures with diffusional closed composition.

Table. 1 Measured thermal conductivities in the wall fragments materials.

	Field no. 1			**Field no. 3**			**Field no. 4**			**Field no. 5**		
Area of Insulation	min λ	max λ	Δλ	min λ	max λ	Δλ	min λ	max λ	Δλ	min λ	max λ	Δλ
	[W/(m.K)]			[W/(m.K)]			[W/(m.K)]			[W/(m.K)]		
infill insulation	0,0387	0,0399	0,001	0,0621	0,0637	0,0016	0,0377	0,0402	0,0025	0,0384	0,0396	0,0012
MDF insulation	0,1044	0,1115	0,007	0,102	0,1076	0,0056	0,1057	0,121	0,0153	0,0994	0,1291	0,0297

To determine the humidity in insulating materials was used the gravimetric method (mass moisture method). This method is based on weighting wet and dry samples [2]. The Fig. 4 shows collecting of samples for gravimetric test, in this case from field no. 5. From each layer were taken three samples - bottom, middle and top. From each wall field were taken 9 samples (1^{st}, 2^{nd} layer of infill insulation and MDF board). The difference between the positions in the layer was not significant. After collecting, the samples were put into hermetic and vapor proof package and brought to the lab. The samples were preciously weighed before placed into the drying oven. For drying was used the drying oven Kendro-Heraeus and for weighting electronic scale Radwag PS 6000/C/2 with accuracy of 0.01 g). The drying temperature for insulating materials is 105 °C. After 24 hours of drying, samples were weighed, and drying and weighting cycles were repeated in the 6 hours intervals. After reaching the constant weight of the samples, the cycle was completed and values recorded. The difference in weight was equal to amount of evaporated water. Mass moisture is defined per formula (1).

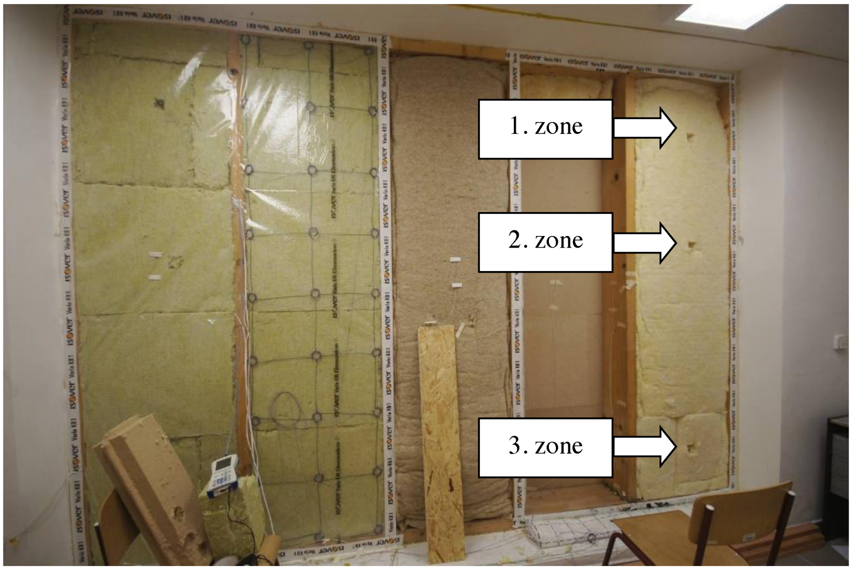

Fig. 4 Test walls from interior and zones of experimental samples for the 5th field (2nd field - optic cables included).

$$w = \frac{m_w - m_d}{m_d} \times 100\ [\%] \tag{1}$$

Measurements of water content in fields 1, 4, 5 (in field 2 there were no measurements performed, because optical cables are used for the measurement and it is not possible to collect samples from it) in fibrous insulations confirmed constant low content (results not published yet) in both measured time periods. On the contrary the increased water content was noticed in hemp layer with diffusional open composition. The mass water content at the wool board oscillated in range of 8.50 % to 13.42 %, while lower values were reached under darker surfaces (Fig. 5 - 1. a 5. field). The highest moisture was recorded again in the part of the diffusional open construction (3rd field).

Table. 2 Measured mass water content in wooden column – head, measured September 2014.

29. sept, 2014	Field no.1	Field no.2	Field no.3	Field no.4	Field no.5	
Top	12,60%	13,00%	11,60%	11,20%	10,80%	11,60%
Center	12,30%	11,30%	12,50%	11,70%	11,80%	11,20%
Bottom	12,80%	12,10%	12,50%	11,70%	12,40%	11,80%

At wooden columns the mass water content oscillated in a range of 10.00 to 15.20 %, which are appreciative values for wood (columns are numbered as in Fig. 2, from the left to the right). Lower values were obtained at fronts of the columns from the interior side as at their sides – measured in the middle of columns (Fig. 6).

Table. 3 Measured mass water content in wooden column – inside, measured September 2014.

29. sept, 2014	Field no.1	Field no.2	Field no.3	Field no.4	Field no.5	
Top	13,80%	14,00%	14,10%	12,60%	12,60%	12,70%
Center	14,30%	14,00%	15,00%	12,80%	13,20%	13,60%
Bottom	14,70%	13,70%	15,20%	14,70%	14,00%	14,50%

With the same methodology the measurement was repeated in May 2015 after the cold period of the year and comparisons of the measured values are shown in Figs. 5 and 6.

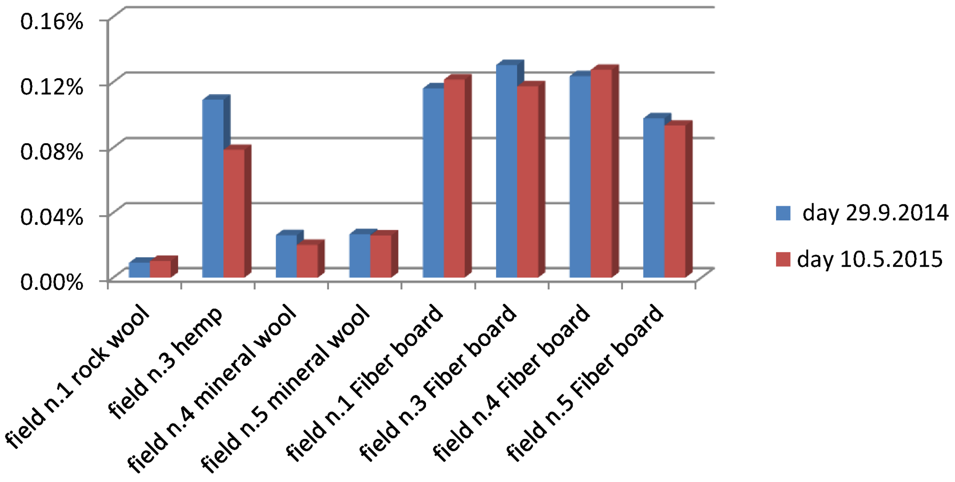

Fig. 5 Water content in thermal insulation in the wall fragments.

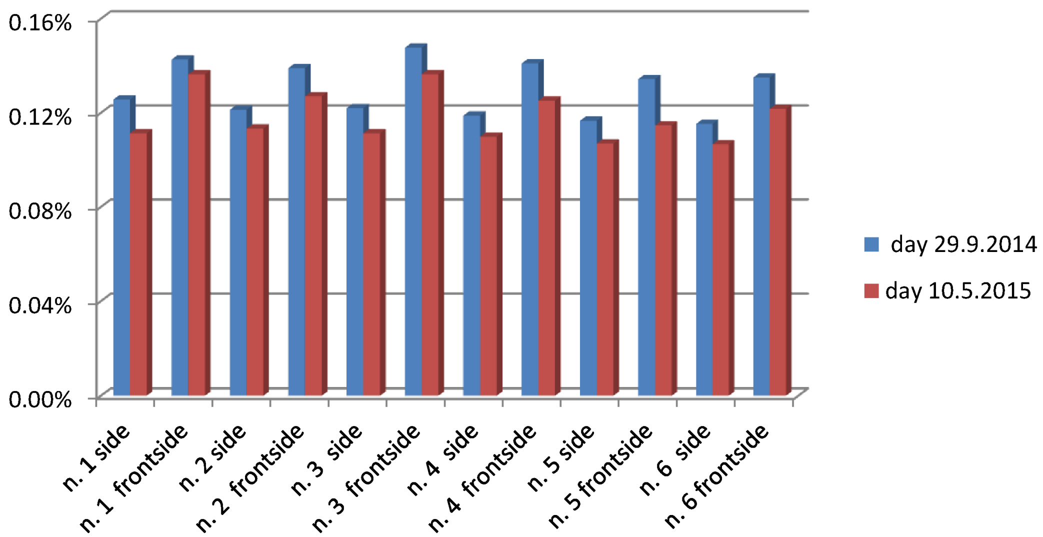

Fig. 6 Water content in wooden columns in the wall composition.

4. Conclusion

During long-term measurements it was shown as expedient to use the unconventional composition with inverse range of layers according to the model of Nordic countries in climate zone of central Europe too. Thermal-accumulative layer was warmed during winter days, which caused the improvement of boundary conditions for heat transport and decreasing of heat losses. Moreover, the negative influence of external environment was decreased (temperature extremes, UV radiation, dust, moisture...) on filling fibrous thermal insulations, which thermal-insulating properties have not changed significantly during the day due to this fact. Moreover, it was thus possible to avoid using OSB board from the exterior side, which has a positive impact not only on moisture transport through the structure, but in economic terms, the absence of one layer has positively influenced both – the amount of acquisition costs and labor content.

Based on the measurements of water content in the insulating materials the following conclusions can be stated: The measured values of moisture in the fields 1, 4, 5 have no significant impact on the thermal conductivity of glass wool and mineral wool (infill insulations). The moisture of glass wool was measured 1.09 % and the thermal conductivity was measured max. 0.039 W/(m.K). The moisture of mineral wool was measured 3.47 % and the thermal conductivity 0.0402 W/(m.K) which are values close to the design values stated in the [6]. These fields were constructed as diffusion closed structures. On the other hand, moisture in the field 3 has a big impact on the thermal conductivity of hemp insulation (11.63 %), because the design thermal conductivity of hemp insulation is 0.04 and the measured one is 0,0637 W/(m.K). That field was constructed as a diffusional open construction.

Color of the facade has an impact on moisture content in MDF board but not on the individual layers of insulation between the wooden poles. The moisture in the MDF boards under the gray plaster was on average 27 % lower than under the white plaster. Also moisture under the yellow plaster was lower but only an average of 9 %.

Measured values of moisture in 3rd and 4th field are nearly the same, which can be influenced by the moisture transport from the wetter 3rd field, because the MDF board is not divided between the fields. The moisture has a big impact on the thermal conductivity of MDF boards (moisture max 13.42 %), the design value is 0.049 W/(m.K) (Table 2), but the measured value is 0.129 W/(m.K) (Tab. 2.).

Measured values of moisture in the wooden construction were less than 15.2 %. Moisture content less than 15.2% does not affect characteristics of wooden structures. Lower values were measured on the front interior surface of the columns of the interior side than on the side edges, measured at the center of the width of columns.

The initial measurements made in September 2014 were repeated in May 2015 after the cold period of the year and do not show significant changes in the increase of the water content, but the opposite, which could be caused by the wet summer and autumn in 2014. In the future, the results will be compared with non-steady heat-air-moisture simulation with measured real outdoor boundary condition.

Based on the research course conclusions for actions in lightweight wall in installed state were formulated. However, it is needed to remark, that these are valid for specific conditions of interior environment of air-conditioned room without presence of thermal gains from internal sources and without thermal gains from solar radiation through transparent constructions.

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